NASA-CR-193515

IN-89-CR
177559

FINAL TECHNICAL REPORT

TO THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SOLAR EXPLORATION DIVISION

P- 8

Submitted to:

Dr. Jurgen H. Rahe, discipline Scientist
Planetary Astronomy Program
Solar System Exploration Division

GRANT AWARD #: NAGW-1408 AWARD PERIOD: 10/1/88 - 9/30/89
NAGW-1913 10/1/89 - 9/30/90

TITLE: Planetary Astronomy of Mars (1408)
Mars Data Reduction (1913)

PRINCIPAL INVESTIGATOR: Robert B. Singer

SUMMARY OF COMPLETED PROJECT:

The first grant referred to above was specifically awarded to obtain telescopic visible and near-IR spectral imaging of Mars during the 1988 apparition (9/28/88). The observing program was highly successful producing approximately 2 Gbytes of data, but was only funded for one year and virtually all of the funds were spent in data acquisition. The follow-up grant was funded the following year for reduction of these data into a scientifically productive form, which because of the size and nature of our observations, was a non-trivial task. A more detailed scientific analysis of these data (fully reduced) is in progress now and will take a number of years. Extended geologic analyses of the astronomical data are being funded by the NASA Planetary Geology and Geophysics program.

The objective was to produce detailed reflectance spectra for contiguous, spatially resolved surface elements covering most of the planet (about +50° to -90° latitude, all longitudes). A total of 6 observing runs, of 3-4 days duration each, were conducted on the University of Arizona's 1.5m telescope on Mt. Bigelow. Please see Table 1 for a summary of these runs. Figure 1 is a sketch map showing the approximate total extent of our spectral image coverage. Nearly all of Mars south of 40° N was observed at least once. About half of the area shown in Figure 1 was observed multiple times. South of 65°S, including the south polar cap, our coverage is heavily redundant. The first run was conducted June 29-July 1, 1988 (all dates are UT) to serve as a baseline prior to possible dust storm activity on Mars. The other observing runs were closer to opposition: Sept. 3-6, 13-15, 24-26, and Oct. 5-7 and 16-18. The September and October observations were scheduled to provide maximum longitudinal coverage. This was also intended to provide a balance between surface observations and observations of predicted dust storm activity. No global dust storm developed in 1988, so we have a large volume of data for the surface of Mars.

(NASA-CR-193515) PLANETARY ASTRONOMY OF MARS. MARS DATA REDUCTION Final Technical Report, 1 Oct. 1988 - 30 Sep. 1990 (Arizona Univ.) 8 p

N94-12768

Unclas

TABLE 1

SUMMARY OF 1988 MARS SPECTRAL IMAGING

Observing Run	Dates	Regions (50 N - 90 S)	Comments	Results
A	6/29 - 7/1/88	10 W - 220 W Amazonis, Tharsis, Olympus, Chryse, V. Marineris, Argyre	poor seeing, some clouds	Fair
B	9/3 - 9/6/88	150 W - 300 W Isidis, Elysium, Phaethontis, Syrtis Major Planitia	some instrumentation problems	Good
C	9/13 - 9/16/88	350 W - 220 W Cerberus, Tharsis, Olympus, Chryse, V. Marineris, Argyre	good run	Excellent
D	9/24 - 9/26/88	240 W - 120 W Tharsis, Chryse, S.Meridiani, Syrtis Major, Hellas	good run	Excellent
E	10/15 - 10/7/88	--------------	bad clouds every night	Support and test data only
F	10/16 - 10/18/88	10 W - 170 W Amazonis, Olympus, Tharsis, Solis Pl., V. Marineris, Argyre	poor weather first two nights, third night good	Good

APPROXIMATE EXTENT OF 1988 SPECTRAL-IMAGE COVERAGE OF MARS

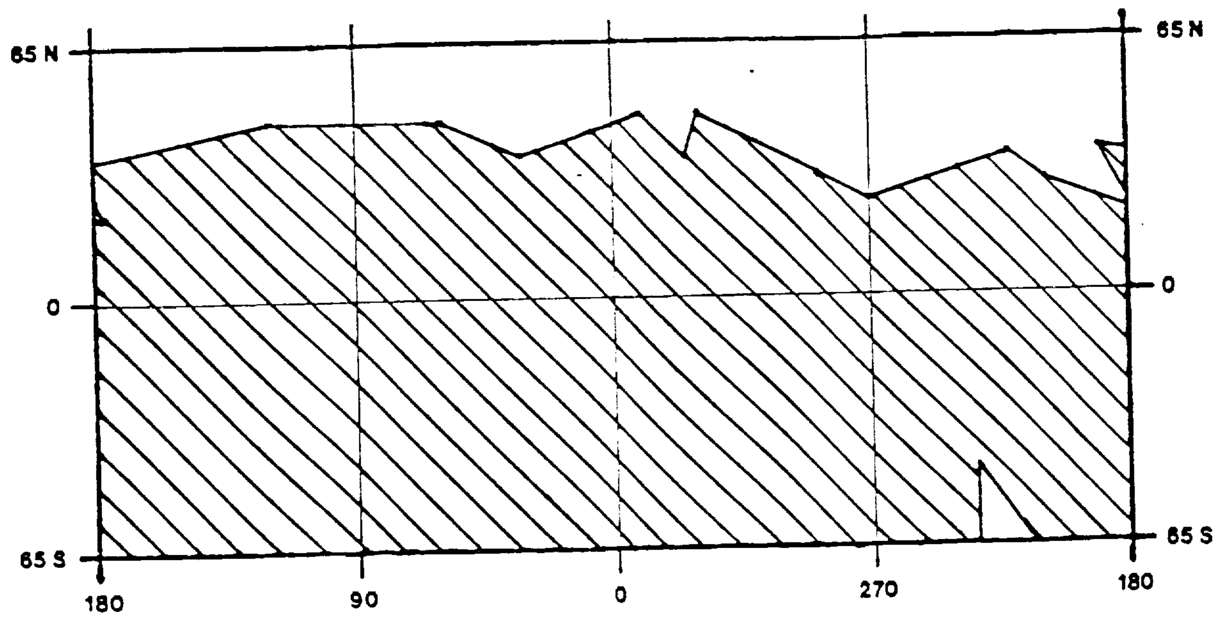

Figure 1 This is a sketch map showing the approximate total extent of our spectral image coverage of Mars during 1988 (cross-hatched area). Nearly all of the planet south of 40°N was observed at least once. About half of this area was observed multiple times. South of 65°S, including the south polar cap, the coverage is heavily redundant.

Instrumentation consisted of an LPL Echelle Spectrograph (D. Hunten) and an LPL CCD system (U. Fink). The spectrograph was used with a prism dispersing element to obtain nearly the entire silicon wavelength sensitivity range in a single exposure. The CCD is an 800x800 element backlit T.I. chip. The variable-width entrance slit of the spectrograph was adjusted to 1.0 arcsecond for observations of Mars and the local extinction standard star (HD4628, F7V). Cross-correlation observations of HD4628 with known solar analog stars HD1835 and 16 Cygni B were performed with the slit set to maximum width (6 arcseconds) to improve photometric accuracy. After the first observing run it became obvious that no single CCD exposure could yield adequate signal/noise in the blue and near-IR without saturating the detector in the central wavelengths, where the combination of instrument reponse and the spectra of Mars and the Sun produced much higher signal levels. For this reason we adopted the practice of taking back-to-back long and short exposures at each slit position on Mars (and the standard stars). These will be combined into single spectra in final data processing. With the slit set to 1.0 arcseconds the true spectral resolution at the blue extreme is about 2nm, while at the infrared extreme the resolution is about 10nm. Spatial resolution across the slit, determined by the 1 arcsecond slit width, is about 250km; spatial detail along the slit is oversampled at 7 pixels per arcsecond, and so is seeing limited. On the best nights we achieved resolution of better than 1 arcsecond, yielding a best case pixel size of about 250km by 150km.

Individual exposures of Mars were obtained with the slit across the planet, producing images with 800 rows of spectral information vs. 300 columns of spatial information along the slit (cropped to include CCD overscan and some sky off each limb of the planet for calibration purposes). Because of speed limitations in CCD readout, display, and writing to disk, as well as some intermittent tracking problems with the 1.5m telescope, we did not use drift scanning to acquire data in the second spatial dimension (perpendicular to the slit orientation). Instead we used an offset guider to accurately manually displace the slit in 1.0 arcsecond steps across the disk of Mars for subsequent exposures. A photographic record of the slit position on Mars was made for every CCD exposure to allow exact locations to be calculated individually, an important factor in accurately mapping surface characteristics. After individual CCD exposures are completely calibrated they will be projected from the orthographic observing geometry to a simple cylindrical map base to build up a 3-dimensional spectral map database. This procedure is time-consuming but will result in more accurate spatial mapping. Time-variable data will not be merged but will be kept separate along a fourth dimension of the database.

Figure 2 demonstrates some of the observing procedures and shows examples of our data. Figure 2a is a photograph of the 1-arcsecond slit positioned on Mars for one specific CCD exposure (visible flaws are due to pits in the stainless steel slit jaws). Such photos were taken for every exposure. The south polar cap is clearly visible. Low albedo features, such as Meridiani Sinus (right center) are less striking in this print but still distinct. Figure 2c is an orthographic projection predictive map for Mars at the time of these observations, based on the Astronomical Almanac, and is useful for orienting oneself. The rectangular box in

.98μ .90μ .48μ

A B C

Figure 2 This demonstrates some of the observing procedures and shows examples of our data. Figure 2a is a photograph of the 1-arcsecond slit positioned on Mars for one specific CCD exposure (visible flaws are due to pits in the stainless steel slit jaws). Such photos were taken for every exposure. The south polar cap and low albedo features, such as Meridiani Sinus (right center) are visible. Figure 2c is an orthographic projection predictive map for Mars at the time of these observations, based on the Astronomical Almanac. The rectangular box represents the approximate extent of the area imaged during this particular observing series. Examples of the actual spectral-image data, combined from 11 separate slit exposures, are shown in Figure 2b. Spatial "slices" are shown for three representative wavelengths, 0.48μm, 0.90μm, and 0.98μm. The excellent spatial and albedo details can be seen, especially in the near-IR.

Figure 2c represents the approximate extent of the area imaged during this particular observing series. Examples of the actual spectral-image data, combined from 11 separate slit exposures, are shown in Figure 2b. Spatial "slices" are shown for three representative wavelengths, 0.48μm, 0.90μm, and 0.98μm. At both of the near-IR wavelengths the spatial detail, contrast, and signal/noise are excellent. Many subtle variations in brightness are visible, and are in excellent agreement with visual observations and the best CCD direct imaging taken in 1988 (e.g. S. Larson, pers. comm. 1988). Meridiani Sinus, Margaritifer Sinus, and even the small dark feature Xanthe Terra are distinctly visible. At the top (north) of these images is the dark region Acidalia Planitia, which appears to blend into the sky background because of limb darkening and the particular contrast stretch used to make these prints. The 0.48-μm image shows a number of differences compared to the near-IR. Because the albedo contrast among Mars surface materials is greatly reduced in the blue, a stronger contrast stretch was used, which also has the side-effect of enhancing the visibility of noise. The major albedo features are still visible, but are more subdued. The northern limb is also of interest because it is quite well defined in the blue. This is because of a lesser degree of limb darkening relative to the near-IR, due to the strong wavelength dependence of absorption in the Fe^{3+}-rich soil and dust. Our preliminary interpretation is that this is partially an atmospheric effect and partially a surface effect. Note that the orthographic spectral image from which these three slices were taken was assembled as a temporary measure. In the final data reduction individual slit exposures will be fully calibrated and projected to a simple cylindrical base map before being spatially combined. This will yield even greater spatial fidelity because small errors in slit location will be treated explicitly.

As of September 26, 1988, there has been no global dust storm activity, nor any regional activity which we have detected. Early June, 1988, a regional storm was reported to have originated in the vicinity of Hellas Basin and which temporarily obscured much of the southern hemisphere (D. Blaney, pers. comm., 1988). By the time of our observations at the end of June surface features and the south polar cap were quite distinct again, although the brightness ratio at 0.8μm between bright and dark regions was only about 1.5 (compared with values of 2.4 measured in late May, 1988 with E. Karkoschka) indicating residual atmospheric dustiness. Our observations in early September also show brightness ratios of about 1.5, consistent with some local dust storm activity reported by amateur astronomers during August (T. Martin, pers. comm. 1988). Despite this dustiness all Mars observers in 1988 measured considerable spatial detail in albedo and spectral properties. Modeling of our data, once calibrated, should allow the atmospheric dust load to be estimated, as well as corrected out of the surface observations.

In these new data a number of important previously known spectral features are seen with improved detail and precision. As expected, the steep visible slope is quite smooth compared with ferric-iron bearing minerals with long-range crystalline structure. However, definite slope changes occur in the data near 0.53μm and 0.63μm, related to incipient ferric-iron crystal-field absorptions. These slope changes are more distinct than seen for the least crystalline Hawaiian palagonites, indicating a somewhat greater degree of crystallinity for weathered dust on Mars. These new data will place far more stringent constraints on laboratory and theoretical modeling to determine Mars surface composition. A number of carefully supervised processing steps are required to produce high-quality, well-calibrated spectrophotometry from these observations.

Results from this observing program have been presented at the following meetings: AAS Division of Planetary Sciences meetings (Singer et al., 1988, 1989, 1990, and 1991); (Miller et al., 1990 and 1991); the 4th Int'l. Conference on Mars held in Tucson, AZ (Singer et al., 1989); the Lunar and Planetary Science Conference held in Houston, TX (Singer et al., 1990); the COSPAR XXVIII Plenary Meeting held in The Hague, The Netherlands (Singer, 1990); the proceedings of Mars Surface and Atompshere Through Time Workshop (Singer, et al., 1991).

SUBMITTED RELEVANT PUBLICATIONS FOR:

NAGW-1408 ('88-'89) and NAGW-1913 ('89-'90)

Extended Abstract:

Spectral Imaging of Mars During the 1988 Apparition. R.B. Singer, E.S. Bus, W.K. Wells, and J.S. Miller, 4th Int'l Conference on Mars, 185-186 (1989).

Visible and Near-IR Spectral Imaging of Mars During the 1988 Opposition. R.B. Singer, J.S. Miller, W.K. Wells and E.S. Bus, Lunar and Planet. Sci., XXI, 1154-1155 (1990); invited final report for NASA Study Project entitled: Mars, Evolution of Volcanism, Tectonics, and Volatiles (MEVTV), LPI Tech. Report 90-06, 273-274 (1990).

Evidence For Crystalline Hematite as an accessory Phase in Martian Soils. Proceedings of Mars Surface and Atmopshere Through Time, 121-122 (1991) (R.B. Singer and J.S. Miller).

Published Short Abstracts and Other Presentations:

Visible and Near-IR Spectral Imaging of Mars During the 1988 Opposition. R.B. Singer, E.S. Bus, W.K. Wells, and C.E. Swift, Bull. A.A.S., 20, 849 (1988).

Unique Spectral Reflectance of Acidalium Planitia, Mars: A Different Type of "Dark Region"? R.B. Singer, J.S. Miller, K.W. Wells and E.S. Bus, Bull A.A.S., 21, 954 (1989).

Visible and Near-IR Spectral Imaging of Mars During the 1988 Opposition. Lunar and Planet. Sci. XXXI, 1154-1155 (1990) and invited final report for the NASA Study Project entitled Mars, Evolution of Volcanism, Tectonics and Volatiles (MEVTV), LPI TEch. Report 90-06, 273-274 (1990) (R.B. Singer, J.S. Miller, W.K. Wells and E.S. Bus).

Global Mapping of Mars Surface Mineralogy. Presented on invitation to COSPAR XXVIII Plenary Meeting (1990).

Observed Variation in Martian Crustal Composition. R.B. Singer, J.S. Miller and W.K. Wells. Bull A.A.S., 22, 1061 (1990).

Ferric Iron Mineralogy on Mars from Spectral Image Analyses. J.S. Miller, R.B. Singer, and W.K. Wells. Bull. A.A.S., 22, 1061 (1990).

Global Mapping of Mars Surface Mineralogy. On invitation COSPAR XXVIII Plenary Meeting, The Hague, The Netherland (1990) R.B. Singer, J.S. Miller, W.K. Wells, and E.S. Bus.

Evidence for Crystalline Hematite as an Accessory Phase in Martian Soils. Submitted to Bull. A.A.S. (1991) (R.B. Singer and J.S. Miller).

Mars: Absolute Calibration of 1988 Visible and Near-IR Spectral Images. Submitted to Bull. A.A.S. (1991) (J.S. Miller, R.B. Singer, W.K. Well, and L. Weller).